MECHANICAL ANALYSES OF SANDS[1]

By Philip Burgess

To the sanitary and hydraulic engineer the period of 1890 to 1895 is of great importance, because it marks the beginning of the present very remarkable growth of water purification plants especially in the United States. English, or slow sand, filters are adapted to the purification of the comparatively clear waters of the Eastern States, where this work received its first important impulse, so that much of the original investigation work along the lines of water purification was directed to the study of filters of this type. The Massachusetts State Board of Health stands conspicuously in the position of pioneer in this work, and its reports, especially for the years 1890–1892, mark a distinct period in the growth of the art of water purification.

Early investigations of this Board and of other workers indicated that the efficiency of a sand filter depends very much upon the size, or range of sizes, of the sand grains composing the filtering material. Consequently, it was necessary to devise some efficient method of analyzing the filter sands for comparative purposes, and the method described by Mr. Allen Hazen in the report of the Massachusetts Board for the year 1892 was developed to meet the requirements which existed at that time. This method proved so satisfactory that it has been generally adopted by the sanitary engineering and chemical professions up to the present time.

Within recent years, however, the engineering field requiring accurate analyses of sands and gravels has broadened very greatly. A comparatively new type of filter, called the American or "Rapid Sand Filter," has been developed and has been found to meet the average requirements in the United States, outside of the Eastern

[1] During the discussion on this paper a motion was made by Mr. Paul Hansen, seconded by Mr. J. M. Diven, that a committee to consider revision of methods of sand analysis be appointed; the motion was, after some discussion, and the suggestion of several names for members of the committee, put and carried.

states, more efficiently than does the English, or "Slow Sand" filter. Experience indicates that the size of the sand required for a rapid sand filter differs materially from that generally used in the construction of a slow sand filter. While the methods of analysis employed for sand used in the slow sand filter may readily be adapted to the analysis of sand required in the rapid sand filter, the usual method of expressing results in terms of effective size is not entirely satisfactory, because the range of sizes of sand permitted in rapid sand filters frequently is very much less than is commonly used in the filtering material of slow sand filters.

Moreover, recent engineering literature contains many references to a still further and, perhaps, more important use for mechanical analysis of sands and gravels, namely, in the selection of materials required for concrete mixtures. It is now recognized that arbitrary standards or proportions for mixing the aggregates required to form water-proof or dense concrete are no longer satisfactory, or to be recommended, because of local differences especially in the size and ranges of sizes of grains or particles composing the large and small aggregates.

A still further use of mechanical analyses of sands is in the preparation of asphalt mixtures such as are required for certain types of street pavements.

In view of the very rapidly increasing use of, and necessity for, accurate analyses of sands, it is remarkable that recent engineering literature contains so little matter describing or discussing the proper methods of making such analyses. On account of the lack of such standard methods, it is not surprising to note that specifications covering the use of such materials frequently are extremely weak and ambiguous. Such weaknesses, of course, tend to increase the cost of work and frequently result in a very unsatisfactory quality of material.

Another feature of the situation, to which the present lack of standard methods of analysis contributes, is the fact that the manufacturers of apparatus required to separate materials into specified sizes, or range of sizes, find it extremely difficult to satisfy the specifications and requirements of engineers in this respect. This is particularly true in regard to the preparation of sands required for filtering material. It is seldom that a local community does not have available, within reasonable distances, satisfactory material as required for the preparation of a filter sand, but, on account of

lack of knowledge on the part of the local contractors, or of the engineers in charge of a particular piece of work, such local sands are seldom used and filter sand is nearly always imported, perhaps from considerable distances and at large expense.

In view of the increasing importance in the matter it is believed that the attention of the engineering profession may at this time very well be directed to the development and adoption of standards of apparatus and procedure required for the mechanical analyses of sands and also to securing a uniformity of terms required for specifications of materials.

It is believed that some of the confusion which has resulted in the matter has been from the adoption of such terms as "Effective Size" and "Uniformity Coefficient" which are applied to sands used for filtering material. These terms, of course, have little or no significance to an ordinary contractor or to the manufacturer who is in the business of screening and sizing sands and gravels.

Moreover, a further confusion has arisen from the endeavor to use the actual sizes of the sand grains rather than the sizes of the openings in the screens. It was early recognized and appreciated that there may be considerable variations in a sieve used for testing purposes in respect to the diameters of the wires and the spacings of the mesh. Consequently it was considered that the nominal spacings of the meshes per inch were of no consequence in determining the separation of a sieve. This view of the matter, of course, required a determination of the relation between the average diameter of the openings and the size of separation of a sieve, or more properly the determination of the actual size of separation of a sieve. Because but few engineers have available the equipment required to standardize sieves, in many instances the results of analyses have been reported in terms of numbers of meshes, or wires, per inch. This method of expressing results, of course, is indefinite and inaccurate, because wire cloth used in the manufacture of sieves frequently varies both as regards sizes of wires and the number of meshes per inch. Within recent years, this difficulty has been appreciated by manufacturers who in some instances have endeavored to clear up the matter by producing standard testing sieves made in accordance with recent standard specifications and with certain arbitrary intervals of spacings between the individual units. By such means, it is hoped to fix definitely the diameter of the openings in testing sieves. Recently, the Bureau of Standards of the

Department of Labor and Commerce at Washington has adopted standard specifications covering the manufacture of certain testing sieves; also, when solicited, this department stands ready to rate and standardize testing sieves at a nominal cost with a view of determining the actual average diameters of the openings.

The writer believes that the engineering profession should adopt a standard method and standard apparatus for making mechanical analyses of sands and gravels. It is believed also that simplicity and accuracy in reporting the results would be obtained by revising the methods commonly used at present to report such analyses. Possibly that feature which would tend most to clear up the situation would be to change the standard of measurement from the size of the sand grains to the size of opening in a sieve. In view of the fact that testing sieves can now be obtained which are composed of wires of uniform sizes and of accurate spacings, in both directions, it follows that such sieves will, within reasonable accuracy, contain openings of a certain definite size. Testing sieves which do not come within such requirements as are contained in the specifications of the Bureau of Standards should be rejected.

One of the difficulties to be encountered in such a change of standard would be to compare previous analyses with present or future requirements and conditions. Some years ago, while at Philadelphia, the writer made a great many tests to determine the sizes of separation of two nests of sieves; also to determine the relation between such sizes of separations and the diameters of openings in the screens. The average ratio of size of separation to size of opening was found to be 1.10 and was a constant within the limits of accuracy which can commonly be secured in making a mechanical analysis of sand.

Some of the finer sieves examined contained twilled cloth and not directly woven cloth. The average ratio of the size of separation of the twilled cloth to the average diameter of the openings was found to be 1.18. This comparatively large ratio of separation to diameter of opening in such sieves has been stated to be one reason why there is no constant relation between the diameter of opening and the separation of a sieve. As a matter of fact, however, no difficulty need be encountered in obtaining directly woven wire cloth even for the fine sieves, so that a nest of sieves may readily be obtained with a practically constant ratio of sizes of openings to sizes of separations throughout.

In determining the relation between the separations and openings in the sieves at Philadelphia, there were counted over one quarter million sand grains and the work extended over a period of two months. The sieves were rated and rerated until the curves of analyses obtained by examinations of the same sample of material by the two sets of sieves coincided throughout their entire length. Great care was taken, also, to secure accurate measurements of the diameters of the wires and of the number of meshes per inch in both directions, from several parts of the area of the cloth.

In the following table are shown ratings of different nests of sieves with which the speaker has from time to time been familiar:

Sizes of Separation of Representative Testing Sieves for Sand Analysis.

MESHES PER INCH	SIZES OF SEPARATIONS IN MILLIMETERS					
	A-1	A-2	B	C	D	E
4				5.6		5.7
10	2.00	2.00	2.19	2.15		2.09
14				1.45	1.45	
18	1.04	1.05	1.07			
24	0.79	0.81	0.81		0.86	0.78
30	0.58	0.60	0.61	0.57	0.58	0.57
40	0.45	0.46	0.48	0.46	0.40	0.45
50	0.31	0.33	0.34	0.37	0.30	0.34
60	0.24	0.30	0.30	0.23	0.27	0.29
80	0.187	0.197	0.190	0.195	0.195	0.193
100	0.153	0.161	0.168	0.160	0.150	0.156
140	0.121	0.117	0.126	0.115	0.120	
200	0.085	0.087	0.104			

The sieves indicated in Columns A-1 and A-2 were used in the office of Hering and Fuller of New York. The ratings in Column A-1 were obtained by counting and weighing the sand grains. The ratings in Column A-2 are of the same set of sieves and were made subsequently by the speaker by measuring the diameters of the openings in the screens and applying the factor 1.10 to the sieves Nos. 10–100 and 1.18 to the sieves Nos. 140 and 200. The ratings in Column B were made by Mr. A. E. Kimberly at the Sewage Testing Station of the city of Columbus, Ohio. The sieves of Columns A and B were made by the same manufacturer, at the same time, under the same specifications. The ratings in Columns C and D

were obtained by the speaker for two nests of sieves used at Philadelphia. The ratings in Column E were determined by Mr. J. W. Ellms for the sieves used in testing the sand required for the Cincinnati Water Purification Plant. Mr. Ellms rated these sieves by measuring the diameters of the openings and applying the above mentioned factors to determine the sizes of separations.

The table serves to illustrate some of the reasons why it is believed that the subject of standard apparatus and standard methods for analysis of sands and gravels is of great importance to the engineering profession at this time.

Attention is drawn also to the marked differences in engineering specifications and requirements for the preparation of sands used for filtration purposes. Frequently such specifications are limited to an expression of the maximum and minimum effective size and maximum and minimum uniformity coefficient.

These terms mean nothing to the ordinary contractor who must furnish the material. It is obvious that the whole question of obtaining satisfactory material would be very much simplified if the specifications would read that a satisfactory sand would be one which contains not more or not less than certain specified quantities as separated by certain standard sieves. Such standard sieves would be available for the contractor, or manufacturer of the material, as well as for the engineer in charge of the work who, under present circumstances and conditions, has the matter almost entirely in his own hands. This is true in regard to specifications for sand required not only for filtering material but also for any other purpose.

It is significant that the difficulties of the present situation are appreciated by some of the manufacturers of screens and testing sieves who have, in some cases, in their trade publications, gone into a discussion of testing sieves rather thoroughly with a view of meeting the demands of the engineering profession. Special reference is made to catalogue A entitled "Testing Sieves," published by a manufacturer of Cleveland, Ohio. This company has placed on the market a set of testing sieves, the finest of which conforms to the No. 200 sieve described in the standard specifications of the Bureau of Standards at Washington, D. C. The intervals between the wires, or the diameters of the openings in the sieves, increase in a certain definite ratio, namely, the square root of 2, or 1.414. This ratio has certain obvious advantages because it permits the

selection of sieves which give accurate ratios of separations of 1.1414, 2, or 4 to 1. These sieves are described in the following table:

Standard Testing Sieves

MESH (NO. PER INCH)	DIAM. OF WIRE (INCH)	OPENING (INCH)	OPENING (MILLIMETER)
	0.149	1.050	26.67
	0.135	0.742	18.85
	0.105	0.525	13.33
	0.092	0.371	9.423
3	0.070	0.263	6.680
4	0.065	0.185	4.699
6	0.036	0.131	3.327
8	0.032	0.093	2.362
10	0.035	0.065	1.651
14	0.025	0.046	1.168
20	0.0172	0.0328	0.833
28	0.0125	0.0232	0.589
35	0.0122	0.0164	0.417
48	0.0092	0.0116	0.295
65	0.0072	0.0082	0.208
100	0.0042	0.0058	0.147
150	0.0026	0.0041	0.104
200	0.0021	0.0029	0.074

It is believed that the adoption of a standard nest of sieves along these lines by the engineering profession would help very materially in securing uniformity in the expression of results of mechanical analyses of sands.

It is, also, believed that there would be a great advantage in simplicity of expression of results of analysis or in the form of specifications covering the preparation of filter sands to the effect that 10 per cent of the sand passes, or shall pass, a standard sieve No. 35, or a standard sieve having an opening of 0.417 mm. diameter, as compared with the usual statement that a sand has, or shall have, an "Effective Size" of 0.46 mm. Moreover, the term "Effective Size" has no significance whatever outside of its application to a filter sand and of itself alone the term is of doubtful value as applied to sands such as are frequently used for rapid sand filters. The range of sizes is believed to be much more significant.

In conclusion, it is the writer's wish to call to the attention of the members of this Association that the matter of standardizing methods of making analyses of sands is of importance to all water works men who have to do with water purification problems. If contractors and water works superintendents understood more about the matter, frequently it would be possible to construct and maintain filtration plants at much less expense than is now required. The matter of obtaining satisfactory filtering material frequently is extremely simple, but has been made difficult by the methods of analysis commonly employed, and by the requirements as to size described in engineering specifications. There is no probability that the engineering profession as a whole will adopt the terms now used in the mechanical analyses of filter sands for the analyses of sands and gravels used for other purposes such as proportioning concrete, paving mixtures, etc., so that uniformity and standardization of the results of such analyses can be obtained only by a revision of present methods.

DISCUSSION

MR. PAUL HANSEN: The Association is greatly indebted to Mr. Burgess for bringing the matter of revised methods of filter sand analysis to its attention. The speaker would like, however, to emphasize that we should not discredit entirely the method that has been hitherto used. Mr. Hazen's method has been developed on scientific lines and will probably continue to be the basis for any revised standard that may be adopted. That Mr. Hazen's method has proven to be a reasonably satisfactory method for sand analysis is attested by the very fact Mr. Burgess mentioned, namely, that there has been very little literature published recently on the subject of sand analysis.

It is also questionable whether the full interpretation of a sand analysis can be reduced to such simple terms that it can be readily made by general contractors. However, there can be no doubt about the fact, that the time has come when certain modifications are desirable, especially in view of the fact that it is possible now—which was not the case formerly—to obtain sieves that are made very accurately and uniformly.

MR. F. C. LEOPOLD: There is no question but that it would cost a good many localities unnecessarily for sand used in their filter

plants by reason of the method of analysis. There are a great many localities where perfectly acceptable sand can be secured for filtration purposes and where fairly satisfactory screening plants are established. The only necessary addition to them would be inexpensive screens to secure the grade of sand necessary. But when you put certain requirements of sand analysis up to the sand producer he throws up his hands and does not want to have anything to do with it at any price; consequently, we have to pay anywhere from $2 to $10 a ton freight on sand that very often could have been had elsewhere at $1.50 freight rate, or less.

It does not make any difference to the filter builder, of course, he does not have to pay it, but whoever is building the plant has to pay it. Still there is absolutely no excuse for requiring something which does not add anything to the efficiency of your plant, and which would prevent a man who can do so from furnishing you material that would adequately fulfill the requirements.

There is another thing that the speaker wants to call attention to, and that is an idea in the minds of some engineers that there are only one or two places that filter sand can come from, and that it does not make any difference whether it fulfills the requirements of their specifications or not, if it does not come from those points it is not satisfactory filter sand. We have found that in our experience, not once, but a number of times, we have been able to produce sand that would fulfill in every way the requirements of the specifications, but because certain filter sand had been demanded, as that or its equal it did not comply with their specifications, necessitating an additional expense anywhere from $2 to $10 per ton freight rate, which is absolutely unnecessary. The speaker fully agrees with Mr. Burgess in his idea that something ought to be done to eliminate the necessity for paying freight rates unnecessarily on sand for this purpose when it can be gotten locally, and just as efficient in every way.

Mr. William M. Jewell: There is no doubt that a great saving, as Mr. Leopold said, can be made in the water works filtration plants by changing to the standards that Mr. Burgess has recommended, and the average sand contractor is very much befuddled over terms which he can never understand, because he has had no technical education; and furthermore, such requirements do not always seem to have a legitimate basis.

Experience has shown that if the uniformity coefficient was based on a higher percentage, say 40, it would be very much better for mechanical filters of rapid type than if based on 10 per cent of the finer material.

In rapid mechanical filters, the washing of the filters is getting down to a point where from three to four minutes' application of water is supposed to be sufficient; and the more we can approach an ideal or uniform size of sand, the better it is going to be for efficiency, when you come to shut off the wash water and restart your filter, you are not going to have a mixture all through the filter bed or the fine material on top. As Mr. Burgess has well said, a standard of 10 per cent effective size is all right for slow sand filters, but it is a little bit out of date. The speaker agrees with Mr. Burgess that the standards ought to be changed.

Mr. George W. Fuller (by letter): The writer is in sympathy with Mr. Burgess' viewpoint in the effort to secure simplification and standardization of sieves used for the mechanical analysis of sands.

Unquestionably it has been a fact in the past that contractors, sand dealers and others have experienced marked difficulty in knowing what was desired by engineers who specified the effective size of sand, uniformity coefficient, and limitations in quantities of sand particles either above or below a stipulated size expressed in fractions of a millimeter. Any procedure which will materially improve this situation, as handled by large numbers of people who now grope more or less in the dark, should certainly be welcome.

On the other hand, it should be kept clearly in mind that methods of measurement used for a period of 20 or 25 years should not be put aside lightly until important practical experience gained in past years, with more or less unsatisfactory methods, can be translated for the benefit of the technician with substantial certainty into terms of the new and improved method of measurement which it is desired to adopt.

It is the belief of the writer that the methods can be improved without sacrificing materially our practical grasp of the significance of the fund of knowledge accumulated in the past.

Mr. Wm. B. Fuller (by letter): The author has brought to the attention of the writer a matter which has for several years occupied his thoughts, and he is in hearty accord with the suggestion

toward the abolition of specifications concerning effective sizes and uniformity coefficients, and the adoption of language more easily understood by contractors and others who have to furnish the materials.

In specifying sands for filter plants, and in mixing concrete, the writer has long since abandoned these confusing terms, having discovered that they acted as bugaboos to the contractor, who, in consequence, bid much higher than was necessary, for fear of money losses, due to possible impracticable enforcement of petty details.

The writer has no doubt that many thousands of dollars would have been saved to communities had all specifications been written so as to state the allowable percentages passing through certain standard sieves. In the absence of such standards the writer has been accustomed to specify the percentages passing a certain number of meshes per lineal inch made from a certain size wire. It is obvious that if a standard mesh was adopted the specifications would become clearer and less cumbersome. Experience in this line leads the writer to believe that the community would receive the benefit of lower costs for equally good work.

The writer is fully in accord with the author's views that, within the limits of such accuracy as can commonly be secured in making a mechanical analysis of sand, a constant ratio can be adopted between the size of separation and size of opening; his own experience leads him to believe that the personal equation of the operator, the methods, and rate of shaking, and other factors, will produce greater variations in the calculated rated sizes, than would be produced by the use of standard sieves by different operators. Great care and thought, however, should be expended by many persons familiar with the use of test sieves before a definite standard should be adopted.

The recommendation of the author towards the adoption of the standard proposed by the Cleveland manufacturing firm should be carefully considered, as the system is very inconsistent in many respects, not the least of which is the fact that such sizes have been selected for the cloth as are not of standard make, and, in order to maintain the openings in a constant ratio, the ratio of width of wire to width of opening is very erratic. This is particularly noticeable with their 6 and 10 mesh and their 28 and 30 mesh.

The writer considers it very necessary for standard sieves that not only the openings of adjacent sieves should bear some definite

mathematical relation to each other, but also that the ratio of width of opening to width of wire should bear some ratio, and, more important than all, the standards adopted should be of weaves from standard sizes of wire. Most wire is now drawn to either the old English or the Brown & Sharp gauges, and, in addition, only certain of these gauge sizes are available to the trade without special orders for large quantities. Standard sieves should therefore be made from stock wire, if possible, otherwise but few firms could afford to keep a stock of wire for this particular purpose, and as a consequence, many sieves would be sold which were not standard.

In connection with standard sieves, it is also necessary to adopt standard methods of shaking, and in this line a mechanical agitator, giving both a semi-rotary and undulatory motion, is desirable.

The writer is of the opinion that the ratio of one sieve opening to that of the next smaller size in the same series should vary gradually through the series from a larger ratio for the larger openings, to a smaller ratio for the smaller openings, and that at the same time the ratio of the size of wire to the size of opening used in any sieve should gradually decrease as the openings become larger.

It would be very desirable that this matter of standard sieves should be taken up in coöperation with the Bureau of Standards of the Department of Commerce at Washington, and with the American Society of Testing Materials, who it would seem would be the logical society to promulgate a standard, as any standard adopted should be adjusted so as to be of use in all industries.

Mr. Allen Hazen (by letter): It may be that when one has proposed a method that has been in very general, in fact, in almost universal use among those having to do with the subject for a period of twenty to twenty-five years, he ought to be willing to see the method discarded and replaced by a newer one. The writer is in this position with reference to the method of mechanical analysis, which is the subject of Mr. Burgess' paper. However, he feels disposed to insist that it be demonstrated that the proposed changes represent a real advance before they are adopted, and in the present case he feels that some of the changes suggested by Mr. Burgess would be unfortunate, and would not mark an advance in the art.

Mr. Burgess speaks of the necessity of having the standards equally applicable to all the various purposes for which mechanical analyses are required. In this the writer fully concurs. The same definition

of size of particles should, if possible, be used in discussing very fine sediments and silts; in discussing materials to be used as foundations; in discussing filter sands; in discussing materials for concrete mixtures, and in discussing materials for asphalt mixtures.

We can here, perhaps, well divide the subject into two parts. In the old method of sand analyses developed by the writer, the size of grain was defined in all cases as the diameter of a sphere of equal volume. This method is an absolutely general one, applicable to all cases, and the writer sees no reason why it should be abandoned at this time.

The second part of the subject relates to the terms "effective size" and "uniformity coefficient." It should be understood that these terms were originated for the purpose of defining filter sands and for no other purpose, and it is to be recognized that they are not necessarily or presumably applicable to discussing sands, gravels or silts for other purposes. If they prove to be useful for some other purpose, there is no reason why they should not be used, but there is no presumption that they have any significance whatever with reference to materials for foundations or asphalt mixtures, or sands and gravels for concrete.

Mr. Burgess' principal proposition relates to the first part. He proposes to abandon the use of sizes of particles which pass or fail to pass the screens, and to substitute therefor the size of mesh of the screen itself.

It may be proper at this point to state that the method of rating sieves originally proposed and in general use is to put a representative sample of sand upon the sieve to be rated, to shake it in a specified manner, and at the completion of such shaking, to give it a slight further shaking, during which the material passing is separately caught, and finally to determine the grain size of these last particles. Experience shows that these particles are nearly all of the same size, and when that size is determined it establishes the size of separation of the sieve. The size of the particles, in most cases, is determined by weighing a certain number of them and computing the average weight, and from that the average volume and the diameter of a sphere of equal volume, which is the basis of the statement. This is a process that can be carried out with quite definite results, and it is the foundation of the whole scheme of rating and grain sizes that has been used.

In practical operations, a method of comparative rating is also

used and has been found helpful. By this system, one set of sieves, dedicated to that purpose and rated with the utmost care by the method first described, is used for comparison with other sieves for which ratings are desired. The same identical sample of sand is sifted through the standard sieves and through those to be rated. This is repeated with several samples of sand selected to show the points of separation of the respective sieves.

The results of the analysis of each sand by the standard sieves are plotted on logarithmic paper, 20-inch base, a large scale being used to allow of the utmost precision. It is found that the analysis of natural sands plotted in this way, including about the finest half of the material by weight, plot in nearly a straight line on this paper and it is possible from the sieves in the standard set to get a very accurate determination of the position of this line at all points. With this line plotted, the percentages of materials passing each of the new sieves are found upon it, and in the opposite direction is found the corresponding size of separation for that sieve.

The size of separation determined in this way is determined with reference to the original or standard sieves. Very great precision is obtainable with careful manipulation. For instance, the difference between a sieve having a separation 0.200 mm. and one having a size of separation of 0.205, should be unmistakably apparent. This degree of accuracy is all that is required for practical purposes.

This method of comparative rating is described at some length, because it has an important bearing upon the question of substituting the size of mesh for the size of separation of the sieve. The size of mesh is computed in a somewhat theoretical way by ascertaining the number of meshes per inch, best obtained by counting blue prints made from the wire cloth, by measuring with a micrometer the diameters of the wires and by computing from these data the average openings in the two directions. They are practically never square. The wires differ in diameter by quite appreciable amounts among themselves and no one has yet found how to weave cloth so that the space between successive wires is always the same. Under these conditions, some openings are larger and some smaller than those computed, and the majority of holes, instead of being square, are more or less out of square.

The particles of sand instead of being spheres are irregular in shape, the long, middle and short diameters for ordinary sands being

approximately in the ratios of 4, 3 and 2. When such ordinary sand grains are shaken upon a mesh that is not quite square, it is found that the size of grains passing is determined by the longest dimensions of the mesh and not by the shortest one. In other words, if the mesh is 0.28 mm. in one direction and 0.30 mm. in the other direction, it is the 0.30 that controls, and the size of separation of such a sieve will be substantially the same as of another sieve 0.30 in both directions, and also substantially the same as the size of separation of sieve 0.30 x 0.25. This is not exactly true, but it is approximately so.

However, even when this matter is taken into account, there are always variations in the sizes of the openings that affect to an appreciable extent the size of separation of the sieve. For instance, if from a very carefully woven piece of wire cloth, woven for the express purpose of making sieves, and with the greatest attention to having it uniform throughout, a dozen pieces are cut close together and made into sieves and examined by the system of comparative rating mentioned above, substantial differences among the sizes of separation of the sieves are invariably found. These differences are not accidental, such as might be accounted for by differences in manipulation. They are real differences that can be substantiated by passing any number of samples of sand through the same sieves and concordant results can be obtained.

Under these circumstances, to abandon a definite and quite accurate method of designating the size of the sieve and to substitute therefor a less accurate method, is certainly not a step in advance. Examinations of various other kinds of materials involve much labor and equipment. If accuracy is to be secured in such examinations, it is imperative that the fundamental ideas upon which accuracy is based should not be neglected nor abandoned.

It is further to be noted that sifting is only one of various methods used in determining the size of particles. For instance, it is not practically applicable to particles much less than 0.10 mm. in diameter. For all smaller particles elutriation or microscopical methods must be used. Such small particles have little significance in filtration work, but in studies of materials for other purposes they are exceedingly important, and it seems desirable to the writer that the method used should be a general one that does not need to be varied for different purposes. The size of sieve opening being

about 90 per cent of the size of particle, it would be necessary, in order to keep the results consistent, to use an expression to describe the size of smaller particles something like this:

Size being about 90 per cent of actual size and taken to represent what the size of sieve would be which would pass particles of this size, if such a sieve could be made and used.

Similar definitions would be necessary to describe larger particles separated by round openings in metal discs, which are more convenient and accurate for particles 2 mm. and over in diameter.

The writer is interested in Mr. Burgess' statement that the term "effective size is not entirely satisfactory, because the range of sizes of sand permitted in rapid sand filters frequently is very much less, etc." The writer begs to point out that this is precisely the point where the uniformity coefficient is useful. The need of having some method of expressing the degree of variation in the sizes of the particles of sand was recognized when the present method of sand analysis was devised, and it is no less essential now than it was then. In the light of all the experience in twenty-five years since, and with a study of recent development in the art of statistics and methods of statistical expression, the term "uniformity coefficient" seems to measure up very well to modern standards. It is possible that the words "uniformity coefficient" could be now improved upon. On the other hand, the modern equivalent "coefficient of variation" has a precise definition and it should be used only for exactly what it is defined to mean in books of statistics.

The data of sand analysis cannot be treated in a way so that the "coefficient of variation" can be easily computed. The "uniformity coefficient," however, which is easily determined by the methods now in common use, would be proportional to the "coefficient of variation," if that could be computed, and is equally as useful in the interpretation of sand analyses, and as long as it is not identical, it seems better to retain a distinctive expression for it.

The effective size was defined as such that 10 per cent by weight of the particles were smaller than it. This has seemed to many as a somewhat arbitrary and rule of thumb procedure. However, it was based upon very good underlying data.

The filtering materials for which data were available at Lawrence when the method was adopted comprised sands with quite a wide range in uniformity coefficients. Data for frictional resistance, capillarity, etc., for these sands were available. Comparative studies

showed that if 8 per cent was taken as the limit instead of 10 per cent, an unduly great weight was given to the effect of the finer particles upon the physical properties of the material; while if 12 per cent were taken, the effect of the finer particles was inadequately represented. The Lawrence data were very clear upon this point, and the 10 per cent limit was selected because this brought all the materials for which data were then available into their correct relative positions with respect to frictional resistance and capillarity.

There is no reason to suppose that 10 per cent is a precise mathematical limit always true of all materials. Nevertheless, practical experience extending over twenty-five years and to many thousand samples of sand and the collection of large amounts of additional data on physical properties, has failed to show any way in which the original expression could be improved in a substantial manner.

The writer is interested in the improvement in the methods of weaving cloth for sieves and of the suggested arrangement for a set of standard sieves. The arrangement proposed seems an excellent one, and if it can be carried out to give sufficient regularity in mesh opening, he would heartily support it, but would urge that the sieves nevertheless, be rated in all cases and that the actual size of separation be used in discussing the results, rather than the supposed size of separation computed from the nominal or even the measured average mesh and size of wire.

The writer also notes the suggestion that engineering specifications should be written so as to provide the percentages that should pass sieves of certain sizes. Mr. Burgess has evidently overlooked the fact that all the earlier specifications for sand and gravel drawn in the writer's office, and frequently copied in other early specifications, were drawn in the way which he now proposes. For instance, the Albany filter specifications required that, "The grains . . . . shall be of the following diameters; not more than 1 per cent by weight shall be less than 0.13 mm. nor more than 10 per cent shall be less than 0.27 mm.; at least 10 per cent by weight shall be less than 0.36 mm., and at least 70 per cent shall be less than 1.0 mm. No particles shall be more than 5.0 mm. diameter."

The method was a perfectly satisfactory one and has much merit. As the years have gone by and contractors have become accustomed to the terms "effective size" and "uniformity coefficient," these have been written into the specifications and have taken the place of the longer schedules which had previously been used. The writer

thinks that very little practical difference has been made in this change. No doubt, it is true that many contractors do not fully understand all the nomenclature of sand analysis. That is true of many other parts of our specifications.

After much experience in securing sand under specifications covering, perhaps, the purchase of as large a quantity of sand and at as low an average price as would be represented by the experience of any other office in the country, the writer is unable to say that lack of understanding of these methods by contractors has been a serious obstacle in the prosecution of the business. It is certainly true, as Mr. Burgess suggests, that there are numerous excellent deposits of sand stock all over the United States that have not been used, and that much money could have been saved by more knowledge and better appliances. However, that is hardly the fault of the method of sand analysis. A general raising of the intelligence and information of those who have to do with this subject must be the foundation of improvements in this respect and of a more complete use of natural resources.

Mr. Philip Burgess: Before presenting this paper to this Association, the speaker submitted a considerable number of copies to engineers interested in the subject with requests for their opinion in regard to the subject matter contained in the paper. He was interested to note that in nearly all cases these engineers concurred in the opinion that the methods now in use for analyzing sands and the specifications frequently used by engineers to describe sands may very well be revised, simplified, and standardized. It is, of course, true that any step towards a revision of standards or methods of testing, which have been generally adopted for long periods of time, should be taken slowly and only along the lines approved by the majority of those interested and affected.

Nearly all of the engineers who have expressed opinions in the preceding discussion and otherwise have agreed that the use of terms such as "effective size" and "uniformity coefficient" in engineer's specifications is not to be recommended because these terms are not understood by the manufacturers or contractors who have to supply materials in accordance with such specifications. There remains, therefore, but two possible methods of describing sands or gravels in regard to their size or range of size, namely, by specifying certain definite ranges of sizes of grains or by specifying certain definite

percentages by weight which may be retained upon or pass certain standard sieves. At the present time there are no such standard sieves so that it is necessary to define the range of sizes of grains or particles.

It is, therefore, true that specifications along the lines of certain percentages by weight to be retained upon or to pass certain standard sieves would be a radical departure from current practice which specifies sizes of particles regardless of size of openings of screens through which such particles may pass. [illegible] is this departure from current practice which, of course, should be approached with hesitancy and assurance of advantage before it is taken.

The speaker has called attention to specifications of a certain set of standard sieves which define the sizes and spacings of the wires with a view of illustrating what in his opinion is required at this time, namely, a standard nest of sieves for making mechanical analyses of sands. He does not wish to be understood as arbitrarily recommending the adoption of this particular set of standards although the use of a definite screen ratio has obvious advantages. Mr. Wm. B. Fuller has called attention to certain features of these standards which are objectionable, and especially to the fact that there is not a definite ratio between the sizes of openings in the meshes and the diameters of the wires. As Mr. Fuller very well states, this ratio is important and affects the ratio of the size of separation of a sieve to the average opening in the sieve. It is doubtless true that, in any standards that may be adopted, it will be desirable to maintain as closely as possible a definite relation between the size of opening and diameter of the wire in each sieve. As Mr. Fuller also states, the standards adopted should be based upon wire cloths which are readily attainable from manufacturers.

Mr. Wm. B. Fuller and Mr. Hazen both have called attention to the causes of differences in the determination of the size of separation of a sieve; such differences may be attributed to differences in the sands used for rating; in the personal equation; in the method and rate of shaking, and in other factors. Mr. Hazen very well states that it is possible to obtain very accurate precision in determining the separations of sieves by using careful manipulations; and that, for instance, a difference between a sieve having a separation 0.200 mm. and one having a size of separation of 0.205 should be "unmistakably apparent." The speaker agrees with this statement provided that it is qualified to refer to the use of the same sand by

the same operator using always similar procedure. However, this, of course, is not universally the case, because different operators must use different materials composed of sand varying from sharp to round grains, and because operators do not now use the same procedure and care in obtaining the sample of sand selected to represent the separation of the screen. In other words, in present practice there are introduced two important variables, the one due to different materials, the other due to different manipulations of materials.

The fundamental assumption which is made in rating a sieve is that the sand grains are spheres. This, of course, is not true. Moreover, in some cases, the grains do not even approach spheres. Consequently experience indicates that there always are differences in the sizes of separations of a sieve depending upon the material selected to standardize and rate the sieve. Such differences frequently will amount to very much more than 0.005 mm. mentioned by Mr. Hazen to be "unmistakably apparent."

In order to obtain the accuracy mentioned by Mr. Hazen it is necessary that the sieves be rated with the materials which are to be analyzed.

Mr. Hazen refers to a comparative method of rating sieves which consists in determining the sizes of separations of a set of sieves from a determination of the percentages of separation of a sand which has been previously analyzed by a standard nest of sieves. This, of course, is true whether the size of opening or the size of separation of the sieve is used as a standard of measurement, and does not affect the point at issue.

It is a well known fact that it is not physically possible to manufacture wire cloth containing wires of absolutely uniform size and with absolutely uniform spaces between the wires. Consequently, it is argued that it is not practical or feasible to determine the size of separation by an examination of the cloth to determine the average size of openings. This criticism is undoubtedly true for the very fine wire cloth, but is not thought to be well taken for the comparatively coarse cloth containing 100 or less meshes per inch. It is possible today to obtain the coarser wire cloths woven with sufficient accuracy for all practical purposes.

Mr. Hazen argues that it is not a step in advance to change the standard of measurement from the size of separation to the size of opening because of the fact, as stated above, that the size of open-

ing is a variable, and because the larger openings determine the size of separation of a sieve. This point is well taken so far as it applies as a standard of measurement, but as above stated, it is the speaker's thought that even a greater variable is introduced by using the average diameter of the sand grains due to the fact that these grains seldom are round although they are necessarily assumed to be round in determining the size of separation of a sieve. This error of measurement is believed to be much greater than the error of measurement which might be assumed by determining and using the average diameter of the opening in the wire cloth.

In conclusion, it is believed that the matter may very well be handled in the same manner as has been used by the Bureau of Standards at Washington, D. C., in standardizing cement sieves. This bureau has recognized the fact that the standard 200 mesh sieves as required for cement testing are not uniform, and the bureau has coöperated with 80 laboratories throughout the country to determine the sieving value of the 200 mesh sieves, as used for cement testing. As the result of these experiences, the Bureau first drew up specifications defining the 200 mesh sieve in terms of the sizes and spacings of wires and permissible variations. Subsequent experience indicates, however, that the average opening in a sieve does not necessarily determine its sieving value, so that subsequently, the bureau revised its specifications to include a sieving value based upon certain standard material. At the present time, a standard of fineness has been adopted and standard samples of cement to be used for rating 200 mesh sieves are available at a cost of 25 cents to any one who may desire to check up his 200-mesh sieve.[1] The samples of cement are guaranteed to within 0.2 per cent on the fundamental standards of the bureau. This method of rating is in effect the same as the comparative method of rating sand sieves described by Mr. Hazen.

The speaker can see no reason why a similar method of obtaining standards may not be developed for use in connection with the coarser sieves used for the mechanical analyses of sands. It remains for the engineering profession to determine what sieves may properly be adopted as standards and to solicit the coöperation of the Bureau of Standards in this work. If such a set of standard sieves is adopted

[1] Reference: Technologic Paper No. 42—Bureau of Standards, Washington, D. C.

and if the sieves used by laboratories throughout the country are rated in this manner, it is a comparatively immaterial point whether the standard of measurement used is the size of opening or the size of separation. It is, however, very important that the method of obtaining satisfactory standards be available to every one interested.

Moreover, if such standard sieves are adopted, engineering specifications may be simplified to read in terms of these standards thus eliminating all ambiguity and indefiniteness of meaning.

The speaker is very well aware that Mr. Hazen, Mr. Fuller, and other engineers frequently prepare their specifications for filtering material to read in terms of sizes of grains avoiding the use of the terms "effective size" and "uniformity coefficient." However, it is undoubtedly true that the majority of rapid sand filter plants have been and are being constructed under specifications which contain these terms defining filtering material required. The same thing is true relative to filtering material which is purchased as required to maintain filter plants in operation after completion. Standard apparatus or method of analyses of filter sands certainly would be helpful in many cases in producing satisfactory material at the least cost.

It is somewhat remarkable that so little work has been done to determine the hydraulic values of filter sands and that the results of experiments obtained some 25 years ago have been almost universally accepted and adopted. The speaker is convinced that the term "effective size" as now used is of questionable value; in fact, it is his belief that the hydraulic value of a sand depends upon the average size of the particles and the uniformity of the material and not alone upon the size of the finest 10 per cent of the material.

However, it is not so much the thought to discuss the value of these terms at this time as to call to the attention of the engineering profession the necessity for adopting standard methods of analyzing sands used for all purposes. The necessity for such standards is universally recognized, and it is the speaker's opinion that it is a matter of a comparatively short time until such standards will be adopted.